Anisotropic Minerals

Chapter 5 or Nesse

Anisotropic Minerals

• Differ from Isotropic Minerals because:
  – The velocity of light ______ depending on the direction through the mineral, and
  – They exhibit ________________

Anisotropic Minerals

• On entering an anisotropic mineral light is _____ into two rays that:
  – Have different ______ (and RI’s)
  – Vibrate at _____ to each other

Two rows of dots, with each row corresponding to one of the two light rays formed as the light is split upon entering the calcite.
Double Refraction

Calcite - What happens?

Each row of dots corresponds to one ray, each with its own ______ and ____.

Double Refraction

Calcite – Vibration Direction

The Vibration Direction can be determined using a _______.

The two rays are (have a single vibration direction) and ______ to each other.

Double Refraction

Calcite – Refractive Index

The RI of each ray can be measured, using

One will be higher than the other. The ray with the ______ index is called the ______ ray.

The ray with the ______ index is called the _____ ray.
Anisotropic Minerals

• There are one or two ________ through an anisotropic mineral along which light behaves as though the mineral were isotropic. This direction or directions are called the ______

• Hexagonal and Tetragonal minerals have ___ optic axis and are termed **Uniaxial**

• Orthorhombic, monoclinic and triclinic minerals have ___ optic axes and are termed **Biaxial**

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**CAUTIONARY NOTE**

• Remember the difference between:
  • Vibration direction – side to side oscillation of the electric vector of the plane light, and;
  • Propagation direction – the direction the light is travelling

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Why is Light Split?

• Electromagnetic theory provides insight as to why light is split and why the velocity of the light varies with direction through the anisotropic mineral
  • Strength of chemical bonds and atom density are different in different directions
  • A light ray will ‘see’ different electronic configuration depending on direction
  • The electron clouds around each atom vibrate with different frequencies in different directions
Why is Light Split?

• Velocity of light in an anisotropic mineral is dependant on:
  1. the interaction between the ______________ of the electric vector of the light, and;
  2. the ______________ of the electron clouds.
• Resulting in a variation in ________ with direction.
• ______________ theory can explain why light is split into two rays, each with a different velocity, which vibrate at 90°
Anisotropic Minerals

• The resulting two rays encounter different electronic configurations therefore their velocities and indices of refraction must be different

\[ n = \frac{v_{\text{vac}}}{v_{\text{medium}}} \]

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• There will be one or two __________ in anisotropic minerals which show uniform electron configurations, resulting in the EFS plotting as a _______ rather than an _______

• Lines at _________ to this plane or planes are called the Optic Axis –

   _______________________________________________________________________

   (the mineral behaves as an isotropic mineral)

Interference Phenomena

• Under crossed polars anisotropic minerals display a variety of colours – __________ which are produced as a consequence of the light being _________ into two rays on passing through the mineral

• Examine interference phenomena using monochromatic light and apply the concepts to polychromatic (white) light
Development of Retardation

- Magnitude of the retardation is dependant on:
  - The _______ of the sample (d)
  - The _______ in velocity of the slow (\(V_s\)) and fast (\(V_f\)) rays

\[
\Delta = d(n_s - n_f)
\]
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Development of Retardation

\[ \Delta = d(n_s - n_f) \]

- Relationship \((n_s - n_f)\) is termed \((\delta)\) and represents the difference in the indices of refraction of the slow and fast rays.
- In anisotropic minerals, one path, along the optic axis, exhibits ___ birefringence, others show a ___, but most show an ___ value.
- Maximum birefringence is characteristic for each mineral.
- Birefringence ___ with wavelength of light.

**QUESTION**

We have just observed that upon entering a mineral, light is split into two rays - Fast and Slow.

What happens to the two rays of light (Slow and Fast rays) after they have exited the mineral grain?

Interference at the Upper Polar

When vector components of the slow and fast rays are resolved into the vibration direction of the upper polar, they are in opposite directions and cancel, so no light passes. The vector \(S\), the sum of the two waves, is at right angles to the polar's vibration direction.

The fast and slow rays on exiting the mineral are **IN PHASE**, with the slow ray lagging behind the fast ray by 1 whole wavelength.
Interference at the Upper Polar II

Vector components of the slow and fast rays resolved into the vibration direction of the upper polar are in the same direction, so they constructively interfere to yield R, which passes the upper polar and the mineral appears bright.

The fast and slow rays on exiting the mineral are OUT OF PHASE, with the slow ray lagging behind the fast ray by ½ wavelength.

Interference at the Upper Polar

• In the two cases examined, the sample was a constant thickness and exhibited a constant retardation
• If our sample is ________ shaped, the thickness and therefore the retardation will ______ along the length

Δ – Varies along the length ➔

Quartz Wedge viewed between crossed polars under Red Light

Dark areas where Δ = 0, 1λ, 2λ, etc.
Light areas where Δ = 1λ, 2λ, 3λ, etc.
**Polychromatic or White Light**

- Light of a variety of wavelengths, each of which is split into a slow and fast ray, the retardation is the same for all wavelengths.
- Due to different wavelengths, some reach the upper polar ________ and are cancelled, while others are ________ and are transmitted through the upper polar.
- The combination of wavelengths that pass the upper polar produces the ________ ________.

**Polychromatic or White Light**

- Interference colours depend on the retardation of the slow and fast ray, which reflects:
  - ________, and
  - ________
- Samples of the same mineral will display different interference colours, depending on thickness and the orientation of the sample.
Polychromatic or White Light

- Examining the quartz wedge between crossed polars produces a range of colours.

- At the thin edge, thickness and retardation are ~ 0, all wavelengths of light are cancelled at the upper polar, so colour is black.
- With increasing thickness colour changes from:
  - black to grey to yellow to red and then a repeating sequence from blue to green to yellow to red
  - With each repetition the colours become paler.

Michel-Levy Colour Chart

Quartz wedge viewed between crossed polars.
Order of Interference Colours

• On the colour chart, the repetition of interference colours, from red to blue occurs at retardations of 550, 1100, 1650 and 2200 nm
• Boundaries are used to separate the colour sequence into orders
• 1st and 2nd order colours are vivid
• Higher order colours become progressively more washed out, beyond 4th order the colours become a creamy white

Michel-Levy Colour Chart

Anamolous Interference Colours

• Colours under crossed polars that ________ appear on the colour chart
• Colours result when birefringence and retardation are significantly ________ for different wavelengths of light, resulting in a different complement of wavelengths passing the upper polar, which is perceived as a different interference colour
• Mineral colour also influences interference colour as some wavelengths of light are selectively absorbed by the mineral
  – Green minerals transmit green light, absorb others, resulting in interference colours with a greenish tint
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Anomalous Interference Colours

All images from D. Schulze, 2003

Michel-Levy Colour Chart

Relates: Thickness (d) Retardation (\(\Delta\)) Birefringence (\(\delta\))

\[
\Delta = d(n_1 - n_2)
\]

Birefringence (\(\delta\))

Determining Thickness of a known mineral (Quartz)

Mineral is Quartz

Birefringence \(\delta = (n_1 - n_2)\)

1st order grey, just a hint of yellow
Determining Birefringence of an unknown mineral

<table>
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<tr>
<th>Retardation (nm)</th>
<th>0.000</th>
<th>0.005</th>
<th>0.010</th>
<th>0.020</th>
<th>0.025</th>
<th>0.030</th>
<th>0.035</th>
<th>0.040</th>
<th>0.045</th>
<th>0.050</th>
<th>0.055</th>
<th>0.065</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birefringence (n - n)</td>
<td>sf</td>
<td>0.015</td>
<td>0.075</td>
<td>0.090</td>
<td>0.110</td>
<td>0.135</td>
<td>0.225</td>
<td>0.170</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness (d) in microns</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
</tr>
</tbody>
</table>

Max Birefringence - 2nd order yellow, with a hint of green

Recognizing the Order of the Interference Colour

- Becomes easier with practice and familiarity
  - eg. Distinguishing 2nd order red from 4th order red
- Coloured grains may mask the interference colour
- Look at grain edges vs centres
- 1st order white vs high-order white